VOL. II, No. 1
SPRING, 1954

PUBLISHED
QUARTERLY

RESEARCH TRENDS

CORNELL AERONAUTICAL LABORATORY, INC.
4455 GENESEE ST. BUFFALO 21, N. Y.

What **GOOD** *is there in* **ACCIDENTS ?**

by MAURICE H. SLUD

Air safety research, like medical research, is nourished by catastrophe. Only their unsolved problems, which receive concrete expression in accidents and sickness, can evoke active interest in the form of cash. Their successes are accepted as a matter of course. Both are in the paradoxical position of having solved their most critical problems and then finding they have unmasked serious new problems to which their once effective methods seem unsuited.

Air transportation furnishes some of the most spectacular catastrophes. They are investigated and classified. Periodically they are tabulated. The final scores, often presented in graphs like Fig. 1, constitute what is called the "accident record" or the "safety record," according to the story one is telling.

LET'S LOOK AT THE RECORD

Look at Fig. 1. While the curve was falling, it inspired a gratifying sense of progress which undoubtedly favored the growth of commercial aviation. Later on, when the curve leveled off, one could rejoice that it had happened when safety was at its peak, and enjoy a sense of accomplishment. Now that the record has remained relatively constant for a decade, doubts and afterthoughts have had time to develop about whether the record is good enough, why it doesn't get any better, and what will happen to it when new types of transports and heavier traffic enter an operational system which already seems saturated. This is the field of worry in which new safety problems grow.

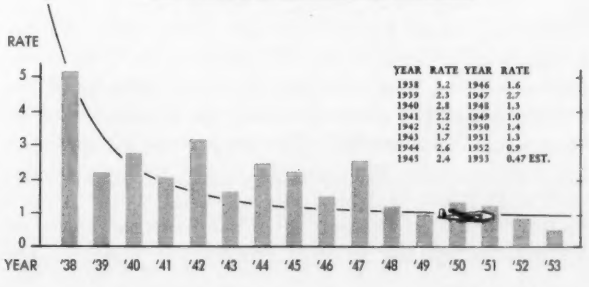
Instead of worrying about the shape of the accident curve of the future, it seems better to inquire how it was given the shape it has. Then perhaps it will be seen how to determine its future.

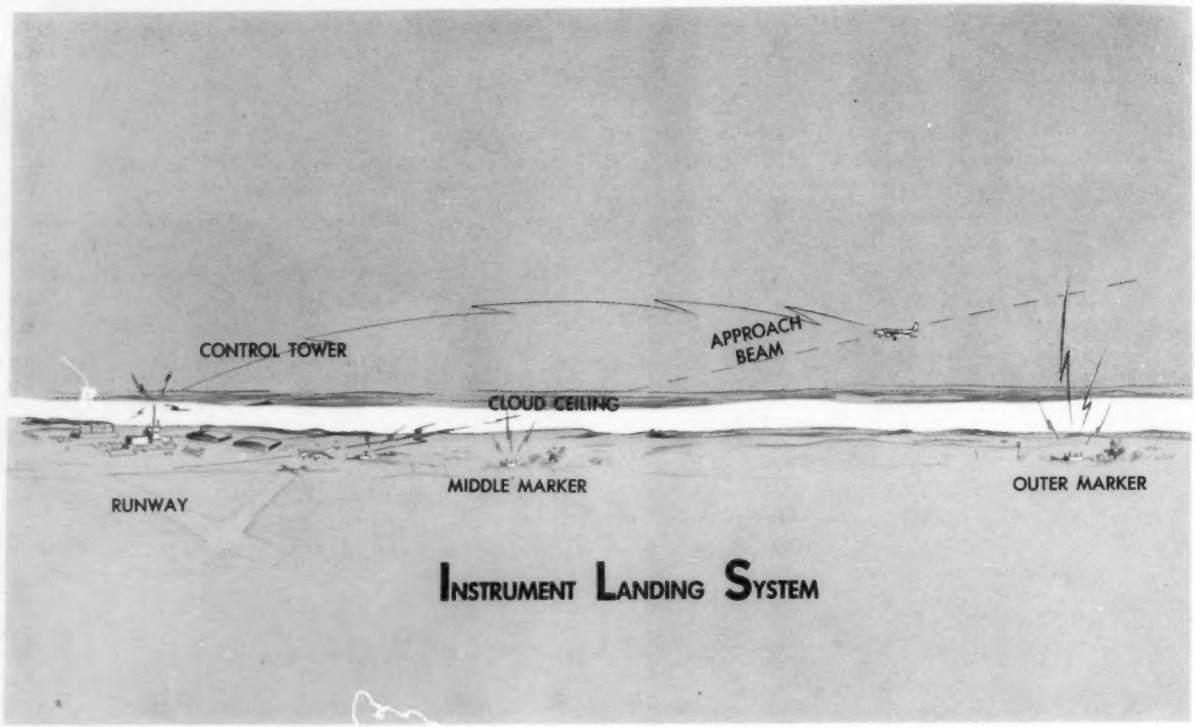
The descent of the accident-curve (Fig. 1) must be ascribed mainly to the achievement of equipment reliability. Much credit must go to the skill with which airline pilots can compensate for certain inadequacies revealed by operational experience, to rising standards of maintenance, to evolution in government standards and regulations, and to the ground aids and the operating procedures which make them an effective system. Nevertheless, primacy must be conceded to the high component reliabilities we now have. They were achieved by systematic trial-and-error on the basis of experience and insight.

How, for example, were airplane engines brought to their present state of perfection? In principle, the process was simple enough. Engines were built, then operated to breakdown. The cause of the breakdown was determined and then either eliminated or circumvented. After this had been repeated enough times, the engine was subjected to operational trials and new failures. Finally, after it was introduced into regular operational use in the airlines, still further modifications were made as the need for them was indicated by operational failures — usually in accidents.

Note, however, that the fact that accidents were involved is rather beside the point, and only came into the picture through the incidental circumstance that an engine failure in an airplane in flight tends to produce an excessively large component of velocity in the vertical dimension. Automobile engines reached high reliabilities through the same process as airplane engines, except that engine failure in an automobile is seldom the cause of an accident.

FIGURE 1
Scheduled Air Carrier Fatalities
Domestic and International Operations Combined
(Per 100 Million Passenger Miles)





INSTRUMENT LANDING SYSTEM

The same process of development still continues, more intensively than ever, for equipment now in operation as well as for new power systems, new communication and navigation aids, etc. It made the accident-curve go down, but apparently it could not keep the curve from leveling off. Why not?

NEW LOOK IN ACCIDENTS

Accident reports contain the simple answer: accidents aren't the same any more. Air accidents used to have a single cause: weather, equipment failure in flight, errors in pilot technique. This is so no longer, at least for the airlines. To the airlines, weather is mainly a cause of delay; equipment failures are the causes of only a minority of accidents. The majority of airline accidents are now operational accidents which differ from the singly-caused type of accident they have largely replaced in that, when they cannot be legitimately ascribed to a definite error of judgment or technique and nothing else, they arise from a breakdown in the relation between a number of interacting factors. The investigation after such an accident reveals a combination of causes, none singly decisive, such that almost up to the moment of impact it would have been practically impossible to say whether there would be an accident or a close shave. When it is hard to see a clear-cut cause, but a misjudgment of the pilot is involved, (as judged after the fact!) the accident is often blamed on "pilot error." This happens so often that it has become rather common, therefore, to say that the central problem in airline safety is that of the human factor. If that is so, then there is no further recourse: we must accept the accident rate as it is, while we try to reform the human element by exhortation or some sort of selective damnation. It is not really as simple as that. Perhaps the easiest way to show the complexity inherent in even a simple operation is by examples.

An important type of landing accident is the overshoot. Some of the factors involved in an overshoot accident are runway length, runway surface, landing speed of the airplane, the pilot's landing technique, the type of airplane (whether it has reversing propellers, for example, and how rapidly and reliably they reverse), the weather, the terrain around the airport. Thus, even in a relatively simple operation, the number of significant factors is surprisingly large, and in any actual overshoot it will be difficult to assign proper weight to their importance, because one or more of them will have combined with what the pilot has been doing, perhaps away back in the approach, to cause an accident. The pilot may have chosen to do as he did because he wanted to avoid another combination of factors which would also have been sufficient to cause trouble. Since, at the present state of knowledge, it would have been impossible to say **a priori** whether the decision was a correct one, in many cases, we see that to assign the blame to pilot error **after the fact** may obscure the essential interconnectedness of the process.

ANOTHER EXAMPLE — BLIND LANDINGS

As a second example, consider the instrument approach to landing. This involves a particular type of airplane (with its specific handling and maneuvering characteristics), the cockpit instrumentation, the pilot and his special technique (which seems to differ with

airplane and airline), terrain, weather, the air traffic control and the radio voice communication system, and ground equipment including two "markers" and the two transmitters which send out the localizer and glide path beams, and the system of approach and runway lights. There may be a radar monitor as well. Then, if the runway is not too long, or if it is slippery, or if the approach is too high, we must consider all the factors mentioned above in connection with the overshoot. It is evident that if a malfunction in the airplane or an unexpected gust were to set off the chain of events leading to a landing accident, it might be very difficult to disentangle the exact course of events, or to assign the true causes with correct emphasis.

Thus, in the annoying field of air operations, the engineer is faced with peculiar difficulties of a sort he did not envisage when he undertook to become an engineer, and which he does not welcome now. Every problem seems to be contaminated with a host of factors he would prefer to consider irrelevant, especially the apparently intractable human element, which is often the dominant one. As in the rest of engineering, one must proceed here by a kind of educated trial-and-error, except that it is no longer always evident what to try, nor can one be sure to recognize an error.

Operational accidents become more complicated as we think about them. Certainly it is clear why the accident record seems to have stopped improving once the simple problems of component failures were solved and replaced by the problems of multiple interactions between machines and man. It is not unduly pessimistic to worry that the increasing speeds, sizes, crowding and complications of the future may make things worse. Let us see whether there is anything to do that will make them better.

ACCIDENTS ARE TOO ACCIDENTAL

To begin with, it is clear that operational accidents cannot assist the engineer in the same way that the simple-failure type of accident did in the past. The engineer concerned with operational accidents cannot find any simple cause of accident and eliminate it, because such simple causes do not exist. Nor can he hope to find important combinations of causes and eliminate them, because the combinations of events leading to an accident seldom or never recur. Furthermore, when one tries at least to single out the dominant causes, even this turns out to be impossible, because the relative significance of accident causes is as various as the variety of operational accidents. Accidents, therefore, are not a suitable subject for study, simply because the word "accident" has no meaning for the engineer, from whose point of view it is a label for a heterogeneous class of unwanted phenomena. What else is there?

In development engineering generally, how do we find our problems? Obviously this is largely a matter of taste and intuition, and there is little that is systematic about it. It only looks systematic after the problems have been solved and put into a textbook. There is no reason to expect anything different in the field of safety engineering in operations, except that operational accidents are very difficult to deal with because it is hard to discover what to try. The safety engineer's inescapable task is to develop an intuition for operations just as in other fields one develops an intuition for how machinery works or how metals deform or what to hook together to make a circuit that will do what is wanted. There is a further difficulty, however.

In air operations, as in all other human affairs, while some questions admit of definite answers, in a great many others the questions asked are questions about probabilities, and to answer them therefore requires statistics and probabilities. For example, when we say that one airport is safer than another (whether this is meaningful or true is now beside the point) we are making an assertion about probabilities. When we say that one procedure for landing on a short runway with a DC-4 is better than another procedure, we are again estimating a probability. Again, if we want to evaluate an instrument landing system, we are not directly interested in computing flight paths. Obviously the flight paths flown in instrument approaches are all different, starting and ending at different points, with different patterns of control movements by the pilots in each approach. When we ask how good the approach system is, we are asking the statistical question: what percentage of all flight paths (compatible with the nature of the landing system, the airplanes to be flown in it, and the methods of piloting) will terminate so that a successful landing can be made?

Now we can state the program of the engineer who wants to raise the level of safety in air operations. He must discover hazards in the operational system, many of which have only a probability of acting (often only a very small probability) in certain situations. Not all will be equally good at this, but it is an ability which develops with use. When he suspects that a particular operation contains an inherent hazard, he will have to use all his knowledge of the structure and operation of the system to demonstrate the extent to which the hazard exists. He must show that in any situation which may occur in actual operations there are appreciable odds of hazard. Whether the hazard will actually play a role in accidents is impossible to predict: accidents are too accidental. Nor is there any great need to make assessments of relative hazard. It is the mere existence of the hazard which demands its removal. When the cost of removal is great, we have a problem of weighing human life against the cost— not an engineering problem at all. In other words, while life constantly demands the taking of risks, in air transportation it is intolerable to take any eliminable risk, however small. Continued improvement of the safety record requires us to learn how to detect and eliminate the risks which are built into the operational system as potential hazards in those rare events we call accidents.

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"Systems Phenomena in Air Operations," Slud, M. H., C.A.L. Report No. JA-848-G-1.

Flame and Flow INTERACTION*

by GEORGE H. MARKSTEIN

The advent of jet and rocket propulsion has greatly stimulated interest in combustion and flame propagation phenomena. Although man has utilized fire since the dawn of civilization, long before many other physical phenomena became useful or even known to him, our understanding of fundamental aspects of combustion is still surprisingly sketchy. In part, the meagerness of our knowledge is probably due to our long history of practical experience with combustion that leads us to take for granted some things that, in reality, are quite complicated or even puzzling. Undoubtedly the main reason, however, is the intricate tangle of physical and chemical phenomena present in what we call "flame," which frequently defies a clean-cut separation into such special fields as thermodynamics, fluid dynamics and chemical kinetics.

Systematic studies of flame propagation in gases date back to the pioneer work of Bunsen, Gouy, Mallard, and Le Chatelier during the latter part of the 19th century. These and many subsequent investigations showed that in general the speed with which a flame spreads through a combustible gas mixture varies widely, even in the course of a single experiment, depending greatly on the particular experimental conditions. Only in certain special cases, notably in a stationary flame burning in a laminar gas stream issuing from an orifice (Bunsen flame), is it possible to measure a velocity of flame propagation which is determined almost exclusively by composition, temperature, and pressure of the combustible gas mixture. This fact led to the idealized definition of "laminar burning velocity" as the speed with which a flat flame front moves perpendicular to its surface into stagnant unburned gas.

Even in the most carefully planned experiment, precision measurements of burning velocity by the Bunsen burner method are beset by troublesome secondary effects, such as curvature of the flame front, entrainment of surrounding gases at the flame base, and flow disturbances ahead of the flame. The result is that seldom, indeed, does a real flame front move with the ideal burning velocity, and far too little is known about the deviations and how to control them. Still farther from a satisfactory solution is the problem of predicting the burning velocity theoretically for any mixture under initial conditions of temperature and pressure, where account must be taken of the simultaneous occurrence of chemical reactions, heat conduction and diffusion in the flame front. Apart from mathematical difficulties, too little is yet known about the complicated chain reactions that take place within the narrow reaction zone of flames. An important role is played in these reactions by various unstable substances that are formed and consumed in rapid succession. These so-called free radicals are too elusive to be observed by conventional chemical means and ingenious methods are needed for their detection and identification. The study of these aspects of combustion is being pursued very vigorously at present by many investigators, employing such varied techniques as emission and absorption spectroscopy and mass spectrography.

FLAME SPEED VITAL TO JET PROPULSION

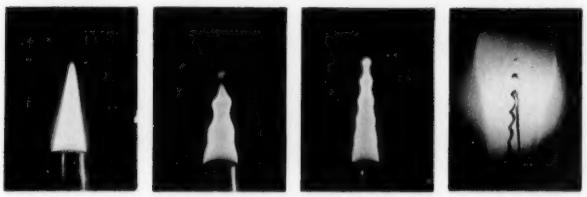
It has already been mentioned that flames propagate with the laminar burning velocity only under rather special conditions. In practically all applications of combustion the "effective" flame speed is much higher than the ideal burning velocity. This is of utmost importance in the field of jet and rocket propulsion for it would be, in fact, quite impossible to burn the necessary amounts of fuel within reasonably short combustion chambers and tail pipes if the ideal burning velocity were not exceeded by a large factor. It is now generally agreed that the rise of flame speed above this burning velocity is due to increased flame surface area, owing to folding and wrinkling, and to enhanced rates of diffusion and heat conduction. Both of these effects are caused by flow disturbances that are usually called, somewhat loosely, "turbulence."

This explanation, however, merely indicates in a qualitative way why flame speeds normally exceed the ideal burning velocity, and to be useful it needs to be supplemented by quantitative theories and experimental data. This task has been attacked only recently. Less than ten years ago turbulence was believed to be essentially an independent initial cause so that to solve this problem one had only to determine the effect of turbulent flow fluctuations, present some distance upstream of the flame, on its rate of propagation. This view had to be abandoned when studies carried out at the U. S. Bureau of Mines and at the Massachusetts Institute of Technology, as well as at this Laboratory, showed that flames are capable not only of modifying profoundly the flow disturbances already present in the approach stream, but of creating spontaneous velocity

*The work described in this article was conducted under the auspices of Project Squid, jointly sponsored by the Office of Naval Research, Department of the Navy, Office of Scientific Research, Department of the Air Force, and Office of Ordnance Research, Department of the Army. The article itself is a modified and up-to-date account of work originally reported in the May 1950 issue of the ONR publication "Research Reviews."

fluctuations in an initially laminar approach flow. These mutual interactions between flame and flow have been the focal point of the flame studies carried out at Cornell Aeronautical Laboratory under Project Squid.

During the early phases of this work, normally steady Bunsen flames burning in a laminar gas stream were subjected to periodic disturbances, and the resulting distortion of the flame front was analyzed by means of stroboscopic observation as well as by high-speed still and motion picture photographs. The effects of various disturbances such as sound waves, alternating electric fields, and vibrating wires were found to be surprisingly similar. In all these cases, the distortion of the flame front consisted of waves which travelled upward along the flame cone with the tangential component of the



a b c d

FIGURE 1 — Effects of periodic disturbances on Bunsen flames: (a) undisturbed flame, (b) stroboscopic photograph of flame under influence of acoustic disturbance, (c) stroboscopic photograph of flame under influence of electric disturbance, (d) spark schlieren photograph of flame disturbed by a vibrating wire.

velocity of the unburned gas. Figure 1a shows a typical undisturbed Bunsen flame; Figure 1b is a stroboscopic photograph showing the effect of sound on this flame; Figure 1c is a stroboscopic photograph of a flame under the influence of an alternating electric potential applied between the nozzle and a spherical electrode. Finally, the spark schlieren photograph, Figure 1d, shows the effect of a vibrating wire touching the flame front near the base.

A remarkable feature, common to all cases investigated and easily seen in Figures 1a-d, was the increase of distortion during the upward travel of the waves. (The increase with time appears of course as an increase in space in the photographs.) It seems obvious that flow disturbances present both in the unburned and burned gases must accompany the observed distortion of the flame front and thus it was conceived that the phenomenon might be quite analogous to the well-known amplification of periodic disturbances in a laminar boundary layer. Tentatively this result was extrapolated to turbulent flames with the conclusion that flames might be capable of amplifying the intensity of turbulence originally present in the approach flow. This conclusion was later confirmed by others in work with actual turbulent flames. The phenomenon was termed "flame-generated turbulence" by these investigators. This concept plays an important role in the current literature on turbulent flames, but is still a somewhat controversial subject.

The distortion of the flame front is evidence of disturbance in the gas flow but it does not follow the motion of a particular gas sample. Thus the change in flame shape does not provide sufficient information for deducing the disturbance velocities, even at the flame front itself. In order to explore the flow patterns in disturbed flames further, titanium tetrachloride vapor, which forms a dense white smoke upon contact with the moisture in the air, was injected into the unburned gas stream in several thin traces. Because the fine smoke particles follow the gas motion practically without any inertia effects, the presence and nature of flow disturbances can be deduced from the shape of the smoke

a b c d

FIGURE 2 — Flow visualization in Bunsen flames by means of $TiCl_4$ smoke traces: (a) undisturbed flame, (b) stroboscopic photograph, acoustically disturbed flame, (c) flash photograph, undisturbed flame, (d) flash photograph, acoustically disturbed flame.

traces. Examples are shown in Figure 2: Figure 2a and the stroboscopic photograph, 2b, are taken in the light of the smoke itself, which becomes brightly luminous in the hot burned gas; 2c and 2d are taken with electronic flash illumination that makes the whole traces, including the portions in the unburned gas ahead of the flame front, visible. The flame front itself is barely seen in these photographs but a break and a change of luminosity is discernible where the traces pass from the unburned gas into the burned gas. Figures 2b and 2d show the effect of sound disturbance on the flow pattern; 2d, in particular, demonstrates strikingly the penetration of the disturbances into the unburned gas. Although the information obtained in this way is of considerable qualitative interest, it is hardly suitable for quantitative evaluation and, therefore, work with this technique was not continued.

FLAME BREAKS SPONTANEOUSLY INTO CELLS

Emphasis was next shifted to the study of flow fluctuations generated spontaneously by the flame without turbulence or other disturbances being present in the unburned gas approaching the flame. This phenomenon was discovered during an investigation of flame propagation in tubes of fairly large diameter. In these experiments the combustible mixture entered a vertical tube near the bottom at a speed low enough to insure laminar flow. Mixture compositions were selected so that the flames burned almost steadily at the top of the tube. Surprisingly, in certain mixtures, instead of retaining a smooth disc-shaped surface, the flame disintegrated into a number of roughly hemispherical "cells" of fairly uniform size. These cells, which were always convex toward the unburned gas, and separated by narrow ridges, filled the whole cross-section of the tube in a single horizontal layer and moved about continuously in irregular fashion. A typical example of

such a cellular flame is shown in the photo insert at the top of the cover page. The flame is burning in a rich mixture (i.e., containing more fuel than necessary for complete combustion) of isobutylene, air and nitrogen in a tube of 10-cm inner diameter.

In spite of the somewhat unruly behavior of these flames, it was possible to measure average cell sizes for various mixture compositions and, by operating the flame tube in the C.A.L. altitude chamber, for pressures down to about 1/3 atmosphere. Moreover, composition limits were established at which the cell structure disappeared and the flame changed into a smooth, continuous disc. The tube method of studying these flames, however, imposed serious limitations on the range of mixture compositions that could be investigated and on the accuracy with which cell size could be measured. These difficulties have now been overcome through the development of a slot burner on which very steady flames consisting of a single row of uniform cells can be obtained over a wide range of mixture composition.

Even before these cellular flames had been observed, "instability" of flames had been predicted theoretically on the basis of purely aerodynamic argument on the one hand and of certain diffusion processes on the other hand. Neither of these lines of approach, however, taken separately, appeared to yield results in agreement with the experimental observations. It was found, however, that reasonable agreement could be achieved when the complex interplay between chemical reactions, heat transfer and diffusion in the combustion zone was taken care of by a relatively simple modification of the aerodynamic stability analysis.

While the experimental and theoretical study of cellular flames thus promises to contribute to our fundamental knowledge of aerodynamic, chemical and transport processes in flames, these more academic aspects might become overshadowed by recently established connections between cellular flame structure and several subjects of greater practical significance. Among these are the already mentioned flame-generated turbulence, and the phenomenon of "vibratory flame movement."

INSTABILITY AFFECTS RESPONSE TO TURBULENCE

One would almost intuitively expect that a flame unstable enough to break spontaneously into cells should respond more readily to the wrinkling effect of turbulent flow than one that normally tends to remain flat and continuous; and recent investigations at the University of Delaware have, indeed, confirmed this hypothesis. As a result, work is now under way on a new theoretical approach to turbulent flame propagation, based on an extension of the analysis of flame stability.

Although flame-flow interactions increase the rate of flame spread in engine combustion chambers, the benefit is frequently offset by undesirable effects leading to combustion vibrations and "rough burning." Much time and effort is currently being spent to eliminate these violent vibrations, primarily by expensive cut-and-try methods. In some instances the causes of these vibrations are now fairly well understood, while in other cases they still remain rather obscure. Systematic studies of vibratory combustion with actual engines is often too expensive and, moreover, the complicated configurations and fuel injection systems of engines make it difficult to separate various participating effects.

At least one important type of combustion vibration, however, can be studied under greatly simplified conditions. If in the flame tube apparatus used for examining cellular flame structure a faster-burning mixture is employed, the flame remains no longer stationary but flashes down more or less rapidly from the open to the closed end of the tube. It was already known to Mallard and Le Chatelier that under these conditions an initial "uniform" movement of the flame is followed by a "vibratory" movement that is generally accompanied by a marked increase of flame speed and may assume a violently explosive character. Extensive study of this phenomenon in the past has shown that the vibration frequencies correspond essentially to organ-pipe oscillations of the gas column in the tube; however, the cause of their excitation and the reason for the simultaneous increase of flame speed has not yet been fully established.

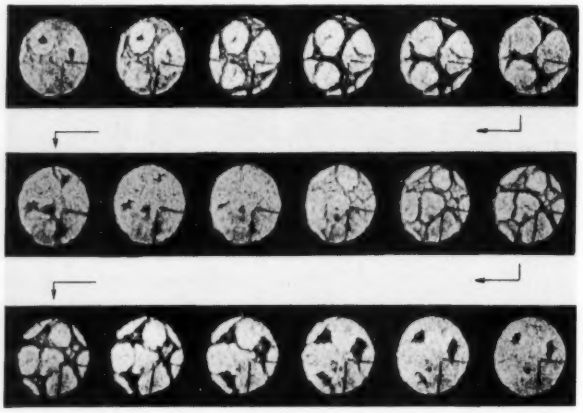


FIGURE 3 — Sequence of high-speed shadowgraph movie frames showing periodically changing cellular flame structure during vibratory flame movement. Frames are taken looking axially through tube of circular cross section. Sequence shows two cycles of oscillation during stage of large amplitude.

STRUCTURE INFLUENCES FLAME VIBRATIONS

Important clues for a better understanding of vibratory flame movement have been provided recently by studying the previously neglected role of flame structure. Because of the extremely rapid changes of flame shape occurring under these conditions, high-speed motion picture methods combined with schlieren or shadowgraph techniques had to be employed. These movies showed that during one portion of the vibration cycle the flame assumed a pronounced cell structure while during the remaining portion the structure disappeared almost completely. This periodically recurrent cell structure behaves quite differently from the "spontaneous" cell structure present during steady-flow conditions. The latter appeared only in certain combustible

mixtures, while the former was always observed during vibratory combustion. The size of the "vibration-induced" cells was primarily related to amplitude and frequency of the oscillation, rather than to mixture composition. With increasing amplitude, the cells grew until only a few remained over the tube cross section. An example of flame structure during vibrations of large amplitude is shown in Figure 3. This sequence of high-speed movie frames was taken by means of a parallel beam of light traversing the flame tube axially and passing through a glass window at the closed end. Figure 3 shows the periodic change of flame structure that takes place during two cycles of the organ-pipe oscillation. In this case the large cells assumed a striking pattern of threefold symmetry.

AN INVOLVED FEED-BACK MECHANISM

These observations called for an extension of the theory of flame stability to the case of a flame front embedded in an oscillating gas column. Because a flame front separates the dense unburned gases from the lighter burned ones, it behaves somewhat like, say, a surface of water in a glass. The oscillation of the gas column, even at moderate amplitudes, exerts alternating accelerations many times larger than the "g" of gravity. Roughly, the effect on the flame can thus be visualized by imagining a glass of water being shaken vigorously up and down several hundred times per second. The resulting periodic distortion of the flame causes it to burn in recurrent bursts rather than steadily. Each burst is accompanied by pressure waves that are sent out into the gases and may in turn reinforce the vibration. This somewhat involved feed-back mechanism explains quite satisfactorily the spontaneous build-up of large amplitude flame vibrations, and a theory based on this model can account well for the experimental observations.

NARROWING THE GAP.

At present, the fundamental studies described above, like similar flame studies being pursued at other institutions, are proceeding independently of current development efforts on rocket and jet engines. Past experience, however, indicates that this gap between fundamental knowledge and engineering requirements will gradually diminish with time. As the gap narrows, it should be progressively possible to replace the cut-and-try methods that today are making the development of new jet and rocket engines so costly and time-consuming. Ultimately, we should be able to establish clean-cut design procedures for such power plants that are comparable to those in use in other fields of engineering.

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About the Authors . . .

MAURICE HOWARD SLUD. Mr. Slud aptly describes his interest in aviation safety as arising "more or less by accident." In a casual look at the field, his eye was struck by something he considered extremely odd — the fact that the operational point of view was usually either underemphasized or ignored entirely when engineers spoke about safety. This, he thought, left a gap which ought to be plugged. Now he thinks it's a chasm.

After garnering an undergraduate degree in Physics and Biology from City College of New York and a Master's degree in Zoology from Columbia University, Mr. Slud spent five years teaching science and mathematics in New York City secondary schools. Heeding a desire for continued study in higher mathematics, he then attended Brown University for three years as a graduate student in applied mathematics financed by fellowships, part-time teaching and research assistantships. Mr. Slud spent a year as lecturer in analytical mechanics and applied mathematics at the Underwater Sound Laboratory under the aegis of Brown University, and served for two years as a research mathematician and lecturer at Catholic University in Washington, D. C.

Mr. Slud joined C.A.L. in late 1950 as a research mathematician. He is presently a member of a systems analysis group of the Special Projects Department, and has been studying this problem of safety in commercial air travel since 1952. His talents include the ability to read Danish, Dutch, French, German, Italian, Latin, Norwegian, Polish, Portuguese, Russian, Spanish and Swedish. Mr. Slud translated the famous Russian monograph of Chaplygin on compressible fluid theory, "On Gas Jets," as well as a chapter of the Russian monograph on plasticity by Sokolovsky. Mr. Slud is a member of the American Mathematical Society and Sigma Xi.

GEORGE HENRY MARKSTEIN. Dr. Markstein's path to research work in combustion hardly has been direct. He received a Doctorate of Technical Sciences from Technische Hochschule in Vienna, Austria, where he studied applied physics under Professor Heinrich Mache, a noted authority in the field of combustion. Markstein's major interest was in the field of radioactivity.

Following his schooling, broad in the typical European custom, he first worked as a research physicist for an incandescent lamp manufacturing corporation in Austria. He left his native Austria in 1938 for South America when the Nazi regime came into power. He spent the next seven years in Bogota, Colombia, where he was active in such varied fields as seismology, radio and electricity, concrete design, plastic molding and paint manufacturing.

Upon joining C.A.L. in 1946 as a senior research physicist in the Aerodynamic Research Department, Dr. Markstein began his work in combustion and flame propagation. He explains this new choice of scientific field merely as being the result of a broad education in applied physics and the interesting appeal of combustion research.

Dr. Markstein was elevated to the post of Head of the Laboratory's Combustion Section in 1949. He is author of numerous papers and reports on flame propagation in gases, cellular flame structure and vibratory flame movement. Dr. Markstein is a member of the American Association for the Advancement of Science, American Physical Society, American Rocket Society and Sigma Xi. He gained his American citizenship in December 1951.

Recent C. A. L. PUBLICATIONS

Requests for copies of the following reports should be directed to the Editor

"A STUDY OF THE FLOW IN A NARROWLY-SPACED RADIAL DIFFUSER," Woolard, H. W., University of Buffalo Thesis (79 pages)

A theoretical method is developed for calculating the radial pressure distribution for laminar flow in a narrowly-spaced radial diffuser having arbitrarily-shaped walls deviating only moderately from a plane surface.

"AN EXACT COMPUTING LINKAGE," Packer, L. S., *Machine Design* (September 1953)

This article describes an exact linkage which is based upon a known generator of the cissoid of Diocles and which may be used to obtain several output displacements which are interesting functions of an input displacement.

"AN INVESTIGATION OF THE RAIN EROSION OF AIRCRAFT MATERIALS AT HIGH SPEEDS," Stutzman, R. H.; Lapp, R. R. and Wahl, N. E., C.A.L. Report PC-743-M-12, WADC Technical Report 53-185 (137 pages)

Erosion, by rain, of the exterior surfaces of high-speed aircraft gives rise to a relatively new problem in aircraft materials. This report discusses recent Laboratory effort toward developing materials more resistant to such deterioration.

"AUTOMOBILE CRASH SAFETY RESEARCH," Smith, A. C., C.A.L. Report YB-846-D-1 (149 pages)

This work was performed for the Liberty Mutual Insurance Company and was directed toward both the control and reduction of bodily injury during a crash as well as toward the reduction of costly physical damage to the automobile.

"DESIGN TRENDS IN FIFTY YEARS—CIVIL AVIATION OTHER THAN TRANSPORT," Wright, T. P., *Aeronautical Engineering Review* (December 1953)

This article is primarily a historical discussion of design trends in personal aircraft. It also discusses briefly the implications of the present status on future trends.

"FINAL DEVELOPMENT REPORT ON STANDARD SUBMINIATURE PACKAGED ELECTRONIC VIDEO AMPLIFIER AND HYDROPHONE AUDIO FREQUENCY AMPLIFIER SUBASSEMBLIES," Welsh, J. P., C.A.L. Report UM-647-D-22 (101 pages)

This report covers the design and development of miniaturized electronic subassemblies which can be mounted in restricted locations and have rapid interchangeability in major units of electronic equipment.

"FINAL REPORT—FLIGHT LINE COMPUTER," (Refinement—Contract NOa(s)-12058) Bogdan, L. and Schultz, E. R., C.A.L. Report IH-705-P-5 (97 pages)

The development and fabrication of a refined airborne instrumentation system for measuring angle of attack, angle of sideslip, true airspeed, relative air density and Mach number are discussed. This airborne device is designed for service application in various fighter-type aircraft.

"INDUCED VELOCITIES GENERATED BY A WING OPERATING IN SUPERSONIC FLOW ON THE BASIS OF LINEAR THEORY," Ferrari, C., translated by R. H. Cramer as C.A.L. Report No. 59 (17 pages)

Results similar to those obtained by Weissenger in the subsonic case are deduced, showing where it is best to locate the lifting line in order to have such an idealization produce the same downwash aft of the wing as would be obtained on the basis of lifting-surface theory. The original Italian report was published in the February 1953 encomium volume of L'Aerotecnica, honoring Prof. G. A. Crocco.

"SPREADING OF SUPERSONIC JETS IN SUPERSONIC STREAMS," Wilder, J. G. and Hindersinn, K., *Aeronautical Engineering Review* (October 1953)

This paper covers a wind tunnel investigation of the behavior of subsonic and supersonic jet streams exhausting into a supersonic stream. The rate of spreading of the jet is determined over a wide range of flow conditions, and a correlation of the experimental results with a theoretical analysis is presented.

"THUNDERSTORM ELECTRICITY," Chapman, S., Chapter IX in *Thundercloud Electrification in Relation to Rain and Snow Particles*, Byers, H. R., editor, University of Chicago Press (1953)

This chapter discusses investigation of the earth's electric field by specially modified radiosondes during thunderstorms and blizzards, and also electrification generated upon disruption of rain drops, including some super-cooled drops.

"Z-AXIS FOR YOUR SCOPE," Ives, R. L., *Radio-Electronics* (November 1953)

An amplifier is described that is designed to insert timing "pips" or "breaks," via the Z-axis, into an oscilloscope record.

Some of the above reports require sponsor's approval prior to distribution.